Acc # 245574

DP-MS-84-119

THE DRY DEPOSITION OF PARTICULATE MATTER ABOVE A LOBLOLLY PINE PLANTATION

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Robert Lorenz and Charles E. Murphy, Jr.

E. I. du Pont de Nemours & Company
Savannah River Laboratory
Aiken, South Carolina 29808

A paper for presentation at the
Seventeenth Conference on Agricultural
Forest Meteorology
Phoenix, Arizona
May 20 - 24, 1985

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

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ABSTRACT

The concentration and type of particulate matter found in the atmosphere varies among localities. The deposition and movement of some types of particulate matter, including pollen, spores and chemical and radioactive aerosols, have been studied by others (Chamberlain 1966, 1969).

Like the transport of water vapor, heat, and momentum, the movement of small particles through the boundary layer above a plant canopy is controlled by eddy diffusion. This is true as long as the particles are less than 50 micrometers in diameter and the turbulent component of the wind speed is not too small (Chamberlain 1975). The movement of particles through the viscous layer surrounding each roughness element is different than the movement of water vapor, heat, and momentum. Surface transport becomes more highly dependent on gravitational, inertial, electrostatic, and thermal forces. In natural systems, both electrostatic and thermal forces have very little effect on deposition rates.

The deposition velocity (Vg) at some reference height z above the stand, usually 1 meter, is defined by

$$Vg = F \;/\; X(z) \qquad (1)$$

where F is the vertical flux to the surface and X is the mass of particulate matter per unit volume of air at reference height z. In this analysis, it is assumed that F is independent of z and advection is ignored. It is also assumed that z is small compared to the distance the particles have traveled.

A concentration/gradient energy balance approach is currently being used to measure the flux density of particles between 0.5 and 20 micrometers above a young loblolly pine plantation. Data collection began in June 1984 and is expected to continue through May 1985. This paper will describe data collection design, transport theory, and an analysis of the data collected to date.

INTRODUCTION

The concentration and type of particulate matter found in the atmosphere vary among localities. The deposition and movement of some types of particulate matter, including pollen and chemical and radioactive aerosols, have been studied previously (Chamberlain, 1975).

Like the transport of water vapor, heat, momentum, and gases, the movement of small particles through the boundary layer above a plant canopy is controlled by eddy diffusion. This is true as long as particles are less than 50 micrometers in diameter and the turbulent component of the wind speed is not too small (Chamberlain, 1975). The movement of particles through the viscous layer surrounding each roughness element is different than the movement of water vapor, heat, momentum, and gases. Surface transport becomes more highly dependent on gravitational, inertial, electrostatic, and thermal forces. In natural systems, such as plant canopies, both electrostatic and thermal forces have very little effect on deposition rates.

The purpose of this study is to determine the flux density and deposition velocity of particulate matter, in selected size classes, above a loblolly pine (*Pinus taeda L.*) plantation. Data from the study will be used, along with other physical parameters associated with the forest ecosystem, to develop models that will describe the deposition of particles to the forest canopy.

A concentration-gradient, energy-balance approach is currently being used to measure particle flux densities and deposition velocities above the forest canopy. Data collection began in June 1984 and is expected to continue through May 1985. This paper describes the data collection design, the transport theory, and an analysis of selected daylight data.

METHODS

In this experiment, the number of particles in six size ranges, the dew point temperature, and air temperature are measured at four heights above the canopy surface. Net radiation, wind speed profile, and soil heat flux are also measured. A microcomputer-controlled data acquisition system, described in another paper presented at this conference (Lorenz and Murphy, 1985) is used to collect the data.

Particle concentrations are determined using a Hiac/Royco Model 4102 optical particle counter equipped with a Model 1200 sensor. In this sensor, particle number is determined by measuring light reflected from particles in the sampling air stream. Particle concentrations are determined from the particle count by making two assumptions: 1) all particles in the sample stream are spherical, and 2) the specific gravity of all the particles is equal to unity.

Dew point is measured using an EG&G Model 300 microprocessor-controlled dew-point hygrometer. Air temperature gradients are determined using five copper-constantan junction thermocouples placed at four different levels above the canopy. Five temperature differences are measured between the four levels, providing some redundancy in the system. Absolute air temperature is determined by two thermocouples located at the lowest measuring height, referenced to an Omega Model 101 Modular Reference Junction.

Net radiation is measured at two points approximately 3 meters from the canopy surface. Soil heat flux is determined by measuring soil temperature at four levels below the ground surface. These temperatures are measured using single thermocouples located at each level that are referenced to an Omega 101 Modular Reference Junction.

Data are collected on clear to partly sunny days. Once the system is started, data are generally collected continuously for 3 or 4 days. All calculations are based on hourly averages of the measured variables.

THEORY

The energy balance of a forest can be defined by the following equation:

$$R_n = lE + C + P_n + S_t \tag{1}$$

where R_n is the net radiation which is equal to the absorbed solar radiation plus terrestrial radiation minus the terrestrial radiation emitted from the forest. The net radiation available at any time is partitioned into latent heat (lE), sensible heat transfer to the atmosphere (C), soil heat transfer (G), net metabolic storage (P_n), and heat stored within the forest canopy and vegetation (S_t). During periods of high solar radiation, P_n and S_t

are comparatively small (Sinclair, Allen, and Lemon, 1975). Therefore, these two storage fluxes are generally ignored when making Bowen ratio estimates of energy and mass fluxes.

The Bowen ratio can be used to measure the partitioning of net radiation between latent and sensible heating of the air as defined by

$$B = C / lE \tag{2}$$

For Equation (2) to be valid, it must be assumed that the diffusivities for heat and water vapor transfer are equivalent. By substituting the Bowen ratio into Equation (1), we can solve for both the latent and sensible heat transfer through a plane above the canopy.

The Bowen ratio approach can also be used to determine the flux density of other atmospheric constituents for which a concentration gradient can be measured above the stand. A ratio of the particle flux density (F_p) to the difference between the net radiation and the soil heat flux density can be calculated. Using the same logic as used in forming the Bowen ratio, this new ratio is assumed to be proportional to the ratio of the virtual potential temperature gradient divided by the particle concentration gradient (dX/dz). Then the particle flux can be calculated from the equation

$$F_p = [R_n - G)dX/dT]/[p\ c_p\ (1/B + 1)] \tag{3}$$

The deposition velocity (v_d) in the boundary layer above the stand is defined by

$$v_d = F_p / X_z \tag{4}$$

where X_z is the concentration of particles at a reference height above the stand, assuming that z is small compared to the distance the particles have traveled.

RESULTS

Figure 1 shows six particle concentration profiles measured on September 27, 1984, between 10 am and 4:30 pm EST. This was a warm, mostly sunny day during a period of extremely dry weather. Particle flux densities and deposition velocities were determined for two particle size classes, 0.5-1.0 and 1.0-2.0 micrometers, respectively. The hourly average particle data during this period are presented in Table 1.

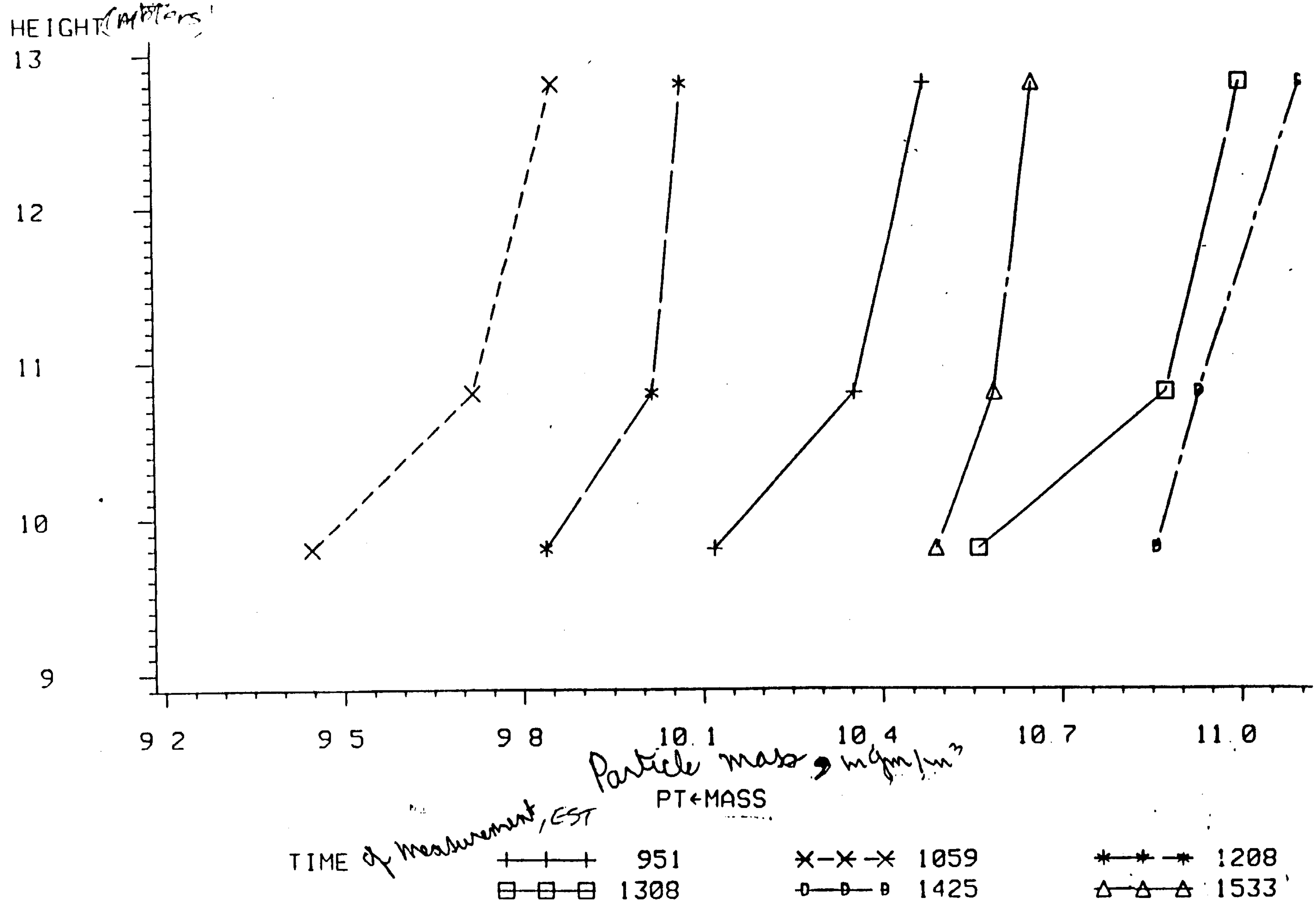

FIGURE 1. **Particle Mass Profiles for the Size Class 0.5-1.0 Micrometers**

TABLE 1

Hourly Particle Data for September, 27, 1984.

0.5-1.0 Micrometer Size Class

Time	Bowen	R_n-G	X	Flux	V_d*
0951	0.16	207	10.4	6.0	0.60
1059	0.25	279	9.8	5.2	0.51
1208	0.61	393	10.0	3.0	0.30
1313	0.79	366	10.9	9.1	0.91
1425	0.89	272	10.8	5.2	0.52
1533	0.14	169	10.7	3.3	0.33

1.0-2.0 Micrometer Size Class

Time	Bowen	R_n-G	X	Flux	V_d*
0951			117	133	1.14
1059			132	36	0.27
1208			129	25	0.19
1313			127	169	1.32
1425			117	47	0.41
1533			109	36	0.33

* units
R_n-G watts/sq. meter
X micrograms/cu. meter
Flux nanograms/sq. meter - sec
v_d cm/sec

The concentration of 1.0-2.0 micrometer particles appears to be higher than average, but may have been influenced by heavy construction about 5 miles away. Bowen ratios are consistent with others measured in this vegetation type (Murphy, Schubert, and Dexter, 1981).

The average daily deposition velocities for this particlular daylight period are 0.35 and 0.61 cm/sec for the 0.5-1.0 and 1.0-2.0 micrometer reporting channels, respectively. These values agree reasonably well with the values reported in the literature for particles in these size classes.

The experimental equipment has reported good particle gradients above the canopy. The system has run with only minor difficulties for 6 months. As soon as these data are analyzed, we will be able to determine the average deposition and the seasonal variation for this forest type.

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ACKNOWLEDGMENTS

This paper was written in connection with work currently being done under Contract No. DE-AC09-76SR00001 with the U. S. Department of Energy.